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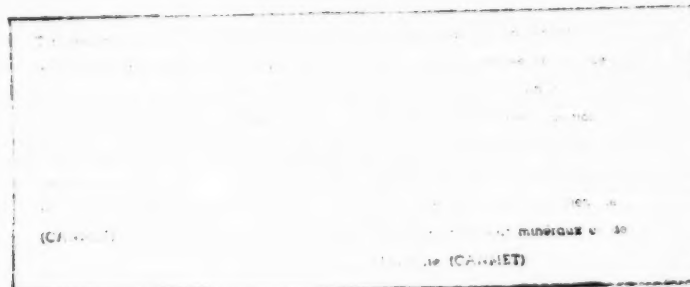
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REMOTE ON-BOARD COAL QUALITY SENSING TECHNIQUES IN COAL CUTTING AND HANDLING SYSTEMS

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by

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ABSTRACT

This review report is basically an introduction to the bibliography placed at the end which lists recent literature concerning remote shortrange coal quality sensors installed either ahead of the cutting head or as a post cutting devices (belt through sensors). Although it is little more than inventory of techniques commercially available, being tested or under development, it is hoped that it may provide a useful summary of the state-of-the-art with respect to on board remote sensing of coal and waste for continuous mining machines.

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UTILISATION DE TECHNIQUES DE TÉLÉDÉTECTION À BORD DES SYSTÈMES DE HAVAGE
ET DE MANUTENTION POUR LE CONTRÔLE DE LA QUALITÉ DU CHARBON

par

J.K. Szymanski*, T.S. Golosinski** et V. Srajer***

RÉSUMÉ

Le présent rapport est essentiellement une introduction à la bibliographie que l'on retrouve dans la dernière partie. Cette bibliographie comprend un répertoire de la documentation scientifique récente sur les appareils de télédétection à courte portée qui peuvent être installés, soit en avant de la tête coupante d'une haveuse ou comme appareil de détection après le havage (capteurs disposés près de la courroie) pour contrôler la qualité du charbon. Ce rapport n'est rien de moins qu'un inventaire des techniques de pointe disponibles sur le marché ou des techniques qui sont encore au stade expérimental ou en voie de développement. Comme il comprend un sommaire pratique des techniques modernes de télédétection du charbon et des déchets, susceptibles d'être installées à bord des machines à fonctionnement continu utilisées pour l'exploitation minière, on espère qu'il sera très utile.

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INTRODUCTION

The inability to accurately sense the geological conditions ahead of selective continuous surface mining machines, severely limits their performance. Prior knowledge of the quality of the material ahead of the machine helps improve performance characteristics and reduce the number of problems during production. The lower level of advance information from external sources makes on board remote sensing very important.

Despite the need for an advance geological condition warning system, it is essential to consider the problem with a practical point of view. The higher level of finesse demanded from a geological condition warning system, will increase cost of the apparatus and, reduce its utilization. It may be necessary to select a less sophisticated but dependable control. For example, with an undercutting drum style of selective continuous surface mining machine, the ideal solution is a remote sensing device ahead of the drum which penetrates the uncut strata and determines the depth to the cut-off horizon. Through a monitoring system the cutter drum can be raised or lowered to maintain the correct cut position. The operating characteristics of such a device are extremely demanding and the absolute accuracy of the device is questionable. The alternative solution could be to monitor the quality of product material passing along the discharge belt of the machine. While there may be inaccuracies in such measurement and perhaps, some material will have been cut by the time a measurement is taken, it is still possible to adjust the cutter and achieve an overall control of quality of the mined product in regular layer cake geologies.

The present report was prepared primarily to document advances in on-board remote sensing systems.

After thorough literature search, it was found that no publication exists that deals specifically with coal quality remote sensing on-board devices.

There is however, a considerable documentation of the cutting horizon measurement methods associated with longwall mining equipment, and coal/waste monitoring techniques in coal handling systems.

COAL ROCK INTERFACE SENSORS

The large interest in monitoring equipment has arisen mainly in connection with longwall remote control and automation. Often when mining through a coal seam, geologic anomalies such as those shown in Fig. 1 are encountered.

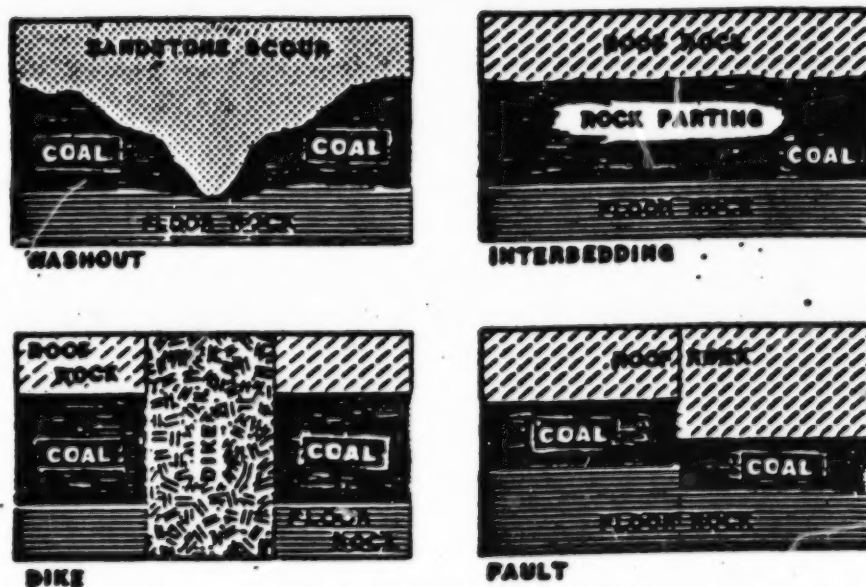


Fig. 1 Typical geologic anomalies found in coal seams.

These geologic disturbances can have an impact on roof control, run-of-mine (ROM) coal quality, production costs, and mine safety; therefore, it is extremely important that mine operators know in advance of mining the geologic conditions which prevail in the coal panel.

Longwall mining equipment is an integrated system consisting of a coal cutting machine (a shearer), an armoured face conveyor, and a series of powered roof supports.

In this section we present a recapitulation and integration of the methods and trends in measurement and subsequent correction of the cutting horizon so that the mining machine can adapt to undulations of the coal seam, and to variations in its thickness. This would mean that the mining machine is able to mine all, or any desired part, of a seam.

The object of horizon control is to maintain the shearer drums of mining machine at the desired position within the seam so that the desired thickness of coal is extracted, so that no waste material from roof or floor is extracted, and so that the desired thickness of roof coal is left intact for improved roof support. This problem has received much attention with numerous sensors being developed. The purpose of these sensors is to achieve one of the following:

- 1) Measure the thickness of coal left in the roof, i.e. the depth to the coal/rock interface. These sensors have been called coal thickness indicators;
- 2) Differentiate between coal and non-coal so that once the coal/rock interface has been reached it can be identified. These sensors have been called surface recognition sensors;
- 3) Indicate the position of the existing roof so that the shearer drum position can be related to it. These devices have been called roof height followers.

GAMMA RAY BACKSCATTER SENSOR

The gamma ray backscatter device (also called the nucleonic coal sensor) has been developed mainly by the UK's National Coal Board and consists essentially of a gamma radiation source that is directed onto the roof material, and a method of radiation detection to monitor the backscattered radiation from the roof. The device is shielded to prevent the monitoring of direct radiation from the source (Figure 2). This device was originally intended to monitor thickness of coal left in the floor. However, the presence of loose coal and debris on the floor adversely affected its accuracy.

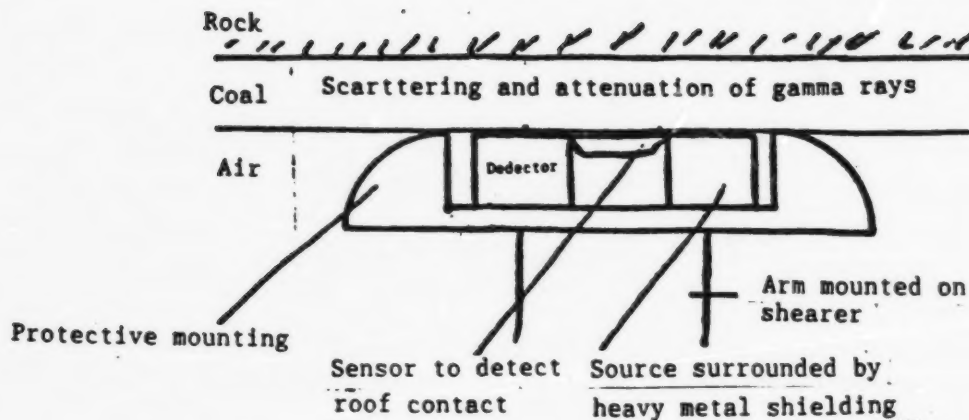


Fig. 2 Representation of the gamma ray backscatter device.

The principle upon which the gamma ray backscatter sensor is based is that when a narrow beam of gamma rays is directed against the rock it is subject to Compton scattering processes and attenuation (i.e. the amount of energy lost per unit path length). The amount of incident rays that are backscattered by the Compton process will be inversely proportional to the density of the scattering mediums (rock type). Attenuation of the radiation will also occur and this will vary according to the relative thicknesses of rock types of different density. Figure 3 indicates the relationship between backscatter and coal thickness. Consequently, any radiation that is detected by the sensor will be related to both the density and thickness of rock type (i.e. coal and non-coal) present.

Several prototypes of this equipment have been investigated in order to optimize coal penetration ranges, equipment weight and source/detector spacing. Various gamma sources have also been tried, including Caesium 137 and Americium 241 (1) while the detector can be either

a Geiger-Mueller Counter or a scintillation counter (2). Of the several instruments designed, the one in most general use is the Probe Type 709. This can measure coal thickness of up to about 200 mm and uses 50 m Ci of Caesium 137 as its gamma source and a scintillation counter using a sodium iodide crystal (2).

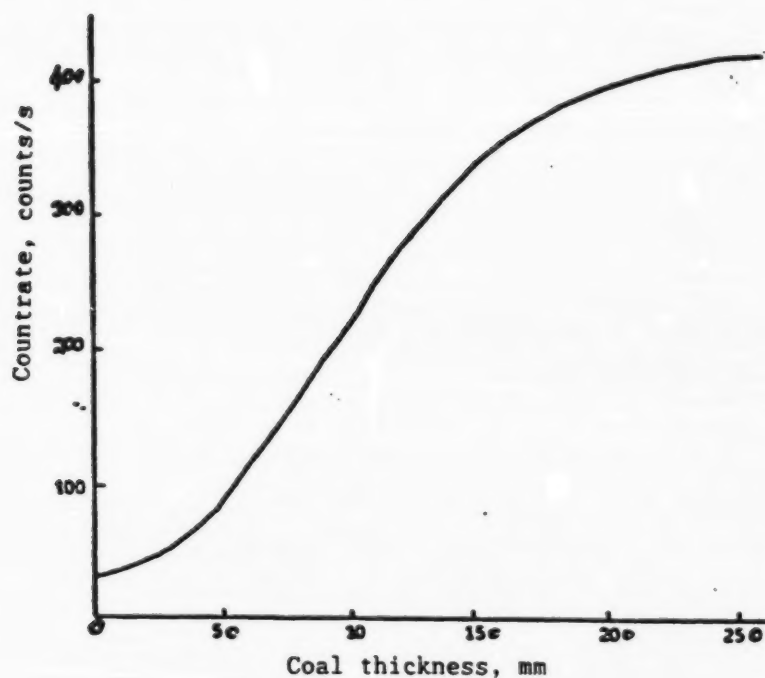


Fig. 3 The relationship between backscatter count rate and coal thickness.

Bennett (3) describes early trials involving the backscatter sensor and a case history of its installation and use has been documented by Smith (4). In practice the sensor is mounted on a hydraulically controlled arm attached to the shearer behind the cutting drum and is held against the roof to maintain sensor-roof contact. The major problems encountered resulted from:

- 1) The inability of the sensor to measure more than a maximum coal thickness of about 200mm to 250mm;
- 2) Difficulty in maintaining a sensor-roof contact. The presence of an air gap affects the count rate and introduces another variable. Observation of Figure 3 shows that a given count rate can represent a variable coal thickness, depending on the presence or absence of an air gap. Additional research into this particular problem has been studied in the USA by NASA's Marshall Space Flight Centre. They have designed and fabricated a two point floating head sensor where the source and detector can move independently of each other to minimize air gaps (1);
- 3) The presence of foreign impurities in the coal seam affecting the reliability of the sensor. This problem imposes a restriction on the number of locations where this type of sensor can be used.

An additional concern would be the potential safety hazard resulting from the use of a radioactive source. All these problems have prompted the investigation of an interface detector based on naturally occurring radiation.

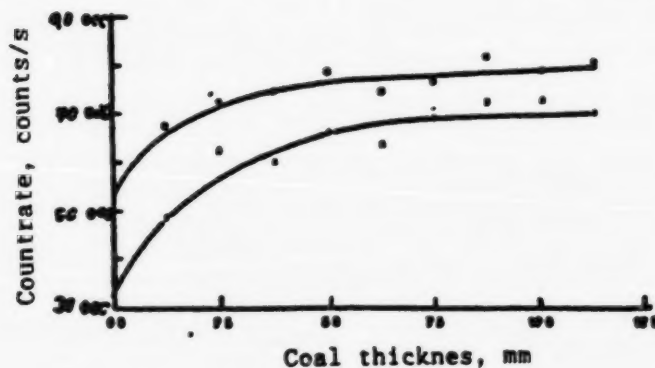


Fig. 4 Effect of air gap on count rate of gamma ray backscatter sensor.

NATURAL GAMMA RADIATION SENSOR

The natural gamma radiation sensor has been manufactured by Salford Electrical Instruments Limited, UK, following development by the National Coal Board's Mining Research and Development Establishment.

The device uses the level of natural gamma emission from the rock above the coal as a means of determining the thickness of coal left in the roof by the previous shear. Many rock types contain quantities of radioactive materials, especially a particular potassium isotope, and the amount varies with rock type; high in shales, medium in sandstone, and low in coal (5). Also the coal will attenuate any radiation that originates within an adjacent rock and the degree of attenuation is a function of coal thickness.

The levels of radiation in rocks overlying coal is very low (typically 20 nCi/kg) and required the development of a very sensitive radiation detection probe. The probe is principally a large scintillation counter employing a caesium iodide crystal, and it is mounted behind the shearer drum within 200mm of the roof. When in use the probe monitors the level of natural gamma radiation penetrating through the coal roof from the overlying rocks, an example relationship between count rate and coal thickness is indicated in Figure 5. It is a necessary condition that the gamma activity in the rock adjacent to the coal is substantially constant over the length of the face. It is also necessary to conduct a preliminary evaluation of the natural gamma activity in the overlying strata in order to program the system.

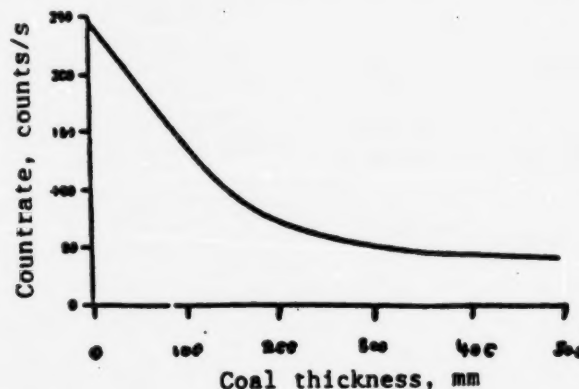


Fig. 5 The relationship between coal thickness and count rate of natural gamma radiation sensor.

In practice the sensor collects data on the present shear roof coal thickness at a position some distance behind the shearer drum cutting the roof. The nominal clearance between the probe and the coal is 200 mm. These data are then stored for use in controlling the height of the drum during the next shear. During this next shear and before the data can be used, it is necessary to know the position of the roof to establish a reference datum. This information can be obtained by a roof height sensor.

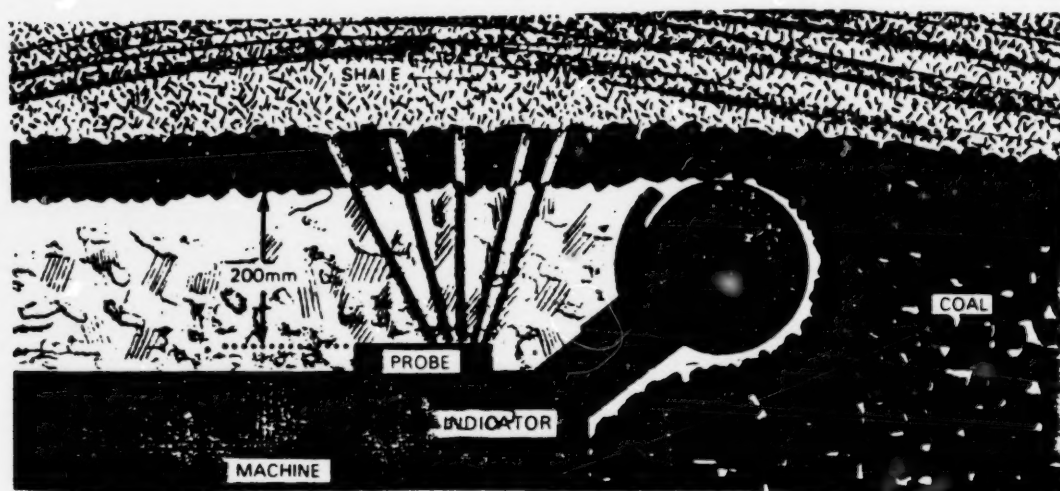


Fig. 6 Type 801 natural gamma coal thickness indication system

The coal thickness indicator is used in conjunction with the natural gamma radiation sensor. It consists of a microprocessor based unit which indicates to the machine operator the deviation from required roof coal thickness. The thickness can be pre-set anywhere within the range of zero to 500mm and the deviation is indicated by light emitting diodes in multiples of 20 mm up to maximum of ± 80 mm (Fig. 6).

The major advantages of the natural gamma radiation sensor over the gamma ray backscatter sensor are seen as:

- 1) No inbuilt radiation source and therefore no hazard;
- 2) The range of coal roof thickness that can be detected is up to 500 mm;
- 3) The sensor is less liable to be damaged as it need not be pressed against the roof.

The equipment has been generally successful during trials, and is capable of being fitted to a range of shearers, both single and double ended. Some problems do occur, however, when friable roof falls away creating cavities. More than 100 of these sensors has now been sold (6).

A similar device is under development in the USA. It employs a sodium iodide crystal in the scintillation counter in (7).

Medium Frequency Electromagnetic Wave Sensors

Electromagnetic wave sensors are based on the principle that differences in the characteristics of coal and shale will cause a reflection of electromagnetic waves at their interface. The time requirement for waves to travel to and from the interface will depend on the propagation velocity of materials involved and the distance of travel. If the propagation velocities are known then the travel distance and position of interface can be determined. Experiments into the application of electromagnetic wave technology for short range sensing are being conducted in the USA (8). The ACE-1 project (technology required for guidance and control of advanced coal extraction equipment) will be based on the following design considerations (8):

- 1) The application of electromagnetic wave technology to sense a rock layer with high electrical conductivity,
- 2) A mechanical design which allows the sensor to withstand extreme abuse,
- 3) Design guidelines that satisfy MSHA permissibility requirements,
- 4) Consideration of human factors associated with the use of the sensor, and
- 5) The ability to sense the distance between the plane of the cutting edge and the coal-rock interface within a range of 2-24 cm.

The sensor is proposed to be mounted on the shearer as shown in Figure 7.

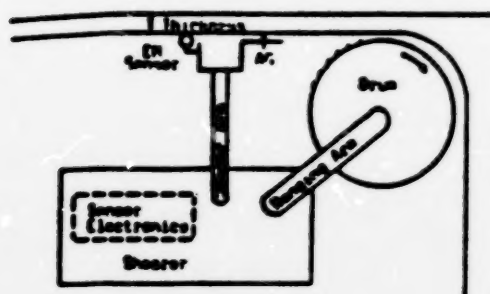


Fig. 7 Front view of shearer illustrating the mounting of the sensor EM source (9).

The sensor's diameter will be approximately 15 cm. The electronic assembly containing the required circuits will be located inside the shearer explosion proof enclosure. The sensor output signal will be connected to the electronic assemblies via a protected coaxial cable in the sensor arm.

An EM sensor will be located in the epoxy filled stainless steel pipe. The air gap (AG) between the sensor and coal layer will remain constant, because of a wheel attached to the stainless steel enclosure which presses against the coal layer. The initial design will feature visual signaling lamps. The sensor's output signal will be an analog voltage that is proportional to the thickness of uncut coal. The signal will be used in the electrohydraulic servo control system to automatically limit the vertical movement of the ranging arm. The horizon sensor will be used in conjunction with MF telecommunications and remote control technology.

Another electromagnetic technique being investigated (10,11) is medium frequency (MF) radio transmission over short-range (10) and long range coal paths in length (11). The feasibility of using MF revealed that the mode has sufficient range for transmission between longwall entries which are normally separated by about 150m. The attenuation rate is sensitive to the coal seam parameters (coal conductivity, rock conductivity, and seam thickness), thus the mode should be useful in sensing variations in these parameters.

Sensitized Pick and Pick Force Sensor

Research into the potential of measuring the cutting force exerted on a special pick sited on the shearer drum, and using this as a measure of the hardness of material being cut, has been conducted in the UK, Federal Republic of Germany, and the USA. Early research in the UK resulted in the development of the sensitized pick (3). Signals from an instrumented pick are indicative of the resistance provided by the rock being cut, and will be related to the rotational position of the pick on the drum. Experimental trials with the pick, conducted at Cotgrave Colliery, UK, indicated some problems (12) but in general the device proved successful and further development resulted in the pick force sensor.

The pick force sensor is again an instrumented pick mounted on the shearer drum and projecting slightly beyond the other normal picks, which monitors the force patterns produced during cutting (13,14). The pick force sensor can be either a piezo-electric device or a strain gauge device with the signal being transmitted via slip rings. The sensor replaces one of the shearing picks on the drum and a pattern of forces on it is generated for each drum revolution. The forces will vary according to the hardness of the strata being cut and the cutting speed. If the cutting speed is kept constant and if the seam contains consistent dirt bands, then the pattern forces may have well-defined peaks which can be correlated for successive drum revolutions as the shearer traverses the face. Now, if a shearer drum is manually positioned and controlled to maintain the desired roof and floor horizons, and if the force patterns are simultaneously monitored, then a "master" face pattern can be produced which is the average pattern derived from numerous drum revolutions. This master force pattern is stored by a microprocessor and can then be used to give a horizon reference. This is done by comparing the actual force pattern with the master, corrective action being taken to maintain the drum on the desired horizon (13).

Examples of measured force pattern and a master force pattern from a surface trial at the Swadlincote Test Site, UK, are given in Figure 8.

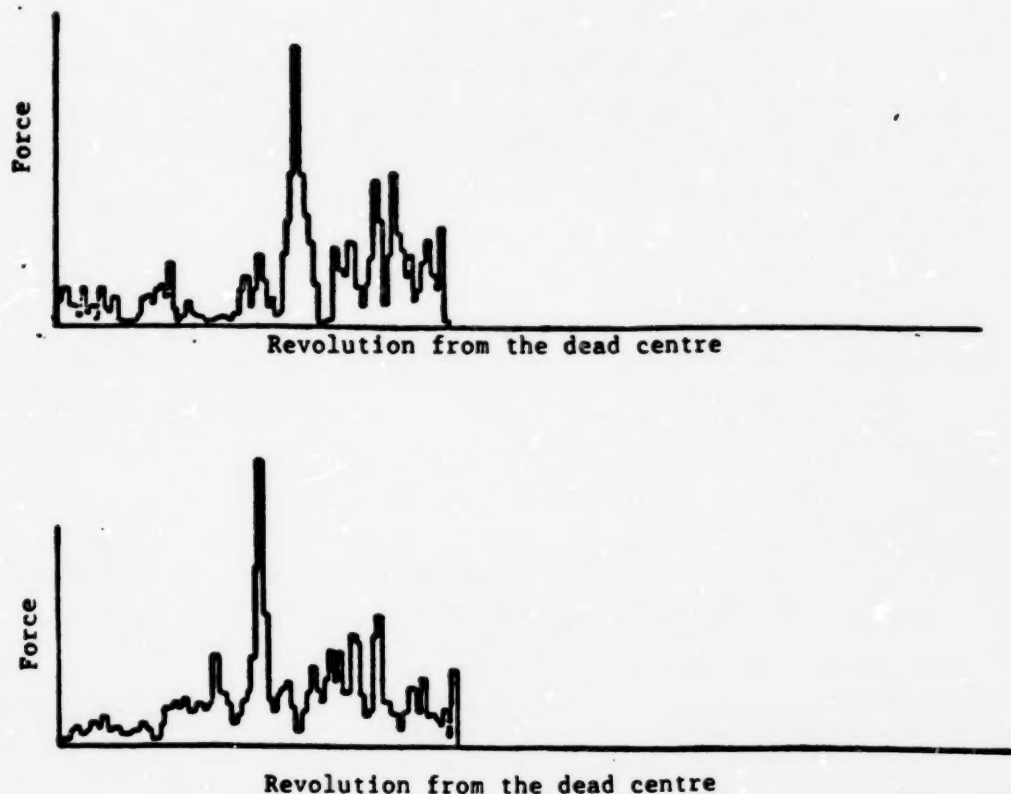


Fig. 8 Examples of face patterns produced by pick force sensor: a) measured force pattern, b) derived master pattern (13).

The vertical displacement from the desired horizon can be identified as a displacement of the peaks in Fig. 7a from their position in Fig. 7b. Pattern recognition techniques can be used to compare measured force patterns.

Underground trials conducted at Florence Colliery and Baddesley Colliery, UK, have indicated the method to be successful in seams with distinctive marker bands, although further refinement appears necessary for seams with no dominant features.

As has been seen, the pick force sensor does not directly indicate the horizon of the cutting drum. This information is obtained by processing the sensor output, and in order to be able to compare this output it is necessary for it to be synchronized with the angular position of the pick around the periphery of the drum as it rotates. This has required the development of a pick position sensor being used with the pick force sensor

(13). The pick position sensor determines when the pick force sensor is at the top dead-centre position during the drum revolution. In this way a reference point can be identified from which the force pattern for any one particular revolution commences. In practice it would only be necessary to monitor the pick forces during the first (cutting) part of the drum revolution.

In the Federal Republic of Germany, Bergbau-Forschung have studied a dual sensitized pick method where two picks are instrumented (12). Although both picks extend beyond the normal picks, the leading instrumented pick is 20mm shorter than the following instrumented pick. In operation the shorter of the two is supposed to cut only coal, while the longer of the two is supposed to cut into the roof rock. Consequently, the two sensitized picks will produce different force patterns. Any deviation from the desired horizon will affect the force pattern as either the shorter pick penetrates the roof rock, or the longer pick no longer penetrates the roof rock.

Work in the USA has mainly been concerned with a strain gauged type of sensitized pick in which the signal is transmitted by both slip rings and telemetry (7, 15). Both methods were found to provide similar data although a problem with the telemetry approach is the limited lifetime of the battery supplying power. Further developments are expected to result in greatly extended battery life, particularly if data from the pick are transmitted for a limited, but relevant, period during the drum revolution (i.e. when the pick is in the region of the coal/rock interface).

Sensitized picks and pick force sensors have a major advantage over many of the other types of horizon control sensors. They provide data for the present shear at the time of cutting, and can be installed on either drum of a double ended ranging drum shearer, thus providing information during the cutting of the floor or roof.

Water Jets

A research project into the use of water jets to locate the coal/rock interface and to measure the thickness of roof coal was conducted at the University of Missouri-Rolla, USA and funded by the National Aeronautics and Space Administration (16).

Earlier research has indicated that when two jets spaced as much as 50mm apart were directed at a piece of coal, the physical properties of the

coal were such that the coal between the two jets would be removed. This behaviour contrasts to that of other rock types where even closely spaced jets (eg. 6mm in sandstone) would leave a rib of undisturbed rock between them. A prototype experimental device was developed whereby a high pressure water jet was rotated so that its vertical axis described a circle of 50mm diameter. If this jet were directed to cut through the roof coal the presumption was that coal would be removed from within the cylindrical jet, but that any non-coal material could only suffer the cutting of a circular slot, thus leaving a central core intact. The resultant geometry of the cut hole is indicated by Figure 9. The position of the coal/rock interface can be identified by the position of the flat end of the cylindrical hole in the coal.

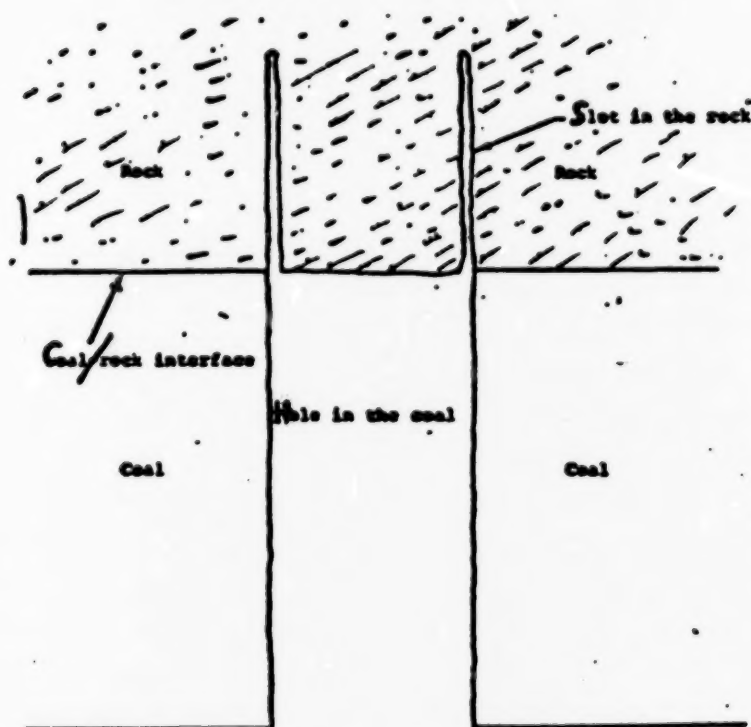


Fig. 9 Cross-sectional geometry of hole produced by water jet to locate coal/rock interface (16).

A test using various nozzle rotation speeds, water pressures and nozzle diameters was conducted in order to optimize these parameters. The studies indicate that it is necessary to use a 1.5 mm diameter jet in order to obtain a satisfactory depth of penetration in the coal, but it is not necessary to use pressures of more than about 42 MPa to penetrate 200mm. Once having cut the hole to the coal/rock interface it is necessary to measure depth of the hole. Of the several methods of measuring this parameter that were investigated, an autofocusing (Honeywell) system used in photography was adopted. This system was found to be advantageous because of its compactness and low cost.

As a result of the experimental program with the prototype, a preliminary design was prepared of a system suitable for use with a shearer. The water jet drilling device was mounted on the shearer body and incorporated a traversing mechanism that compensated for the motion of the shearer, thus maintaining the position of the water jet during its drilling sequence. Behind the water jet drill a small detector was constantly monitoring the depth from the top of the shearer to the roof. Where the water jet had drilled to the coal/rock interface an accurate measure of the thickness of coal left in the roof was obtained.

Vibration Sensor

The General Electric Company, USA, have conducted research into the development of a vibration sensor for horizon control, a project that was funded by the US Department of Energy. The sensor is mounted on the shearer body and, by using differences in the machines vibration characteristics is capable of discriminating between the cutting of coal and the cutting of non-coal, thus indicating the position of the coal/rock interface (1,15,17).

Basically, the sensor consists of an accelerometer mounted on the shearers ranging arm to sense the vibrations, with the monitored data being subjected to appropriate signature processing. Two signal processing systems were studied; a frequency domain technique and a time domain technique. The frequency domain technique is based on the vibration amplitudes at resonant frequencies and since the resonant frequencies depend on details of bit and drum design, the device requires fine tuning for each model of shearer. Figure 10 is an example of the output of a vibration sensor using the

frequency domain technique. The two horizontal lines represent the two interface set points. Such set points are determined practically by positioning the cutting drum to cut into the rock and then adjusting the set point. Both shale (harder than coal) and clay (softer than coal) can be accurately detected.

The time domain technique is based on the level of amplitude modulations in the vibration signal and is relatively independent of shearer design. Because of this advantage the time domain techniques have been favoured and four prototype devices have been constructed for field evaluation in both the USA and UK. Figure 11 is an example of the output of a vibration sensor using the time domain technique. The horizontal lines here represent interface or idle set points.

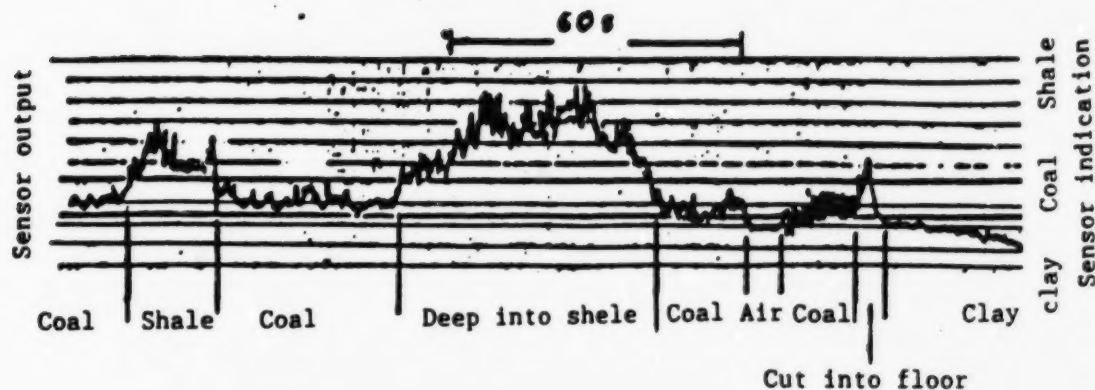


Fig. 10 Example output of a vibration sensor using the frequency domain technique (17).

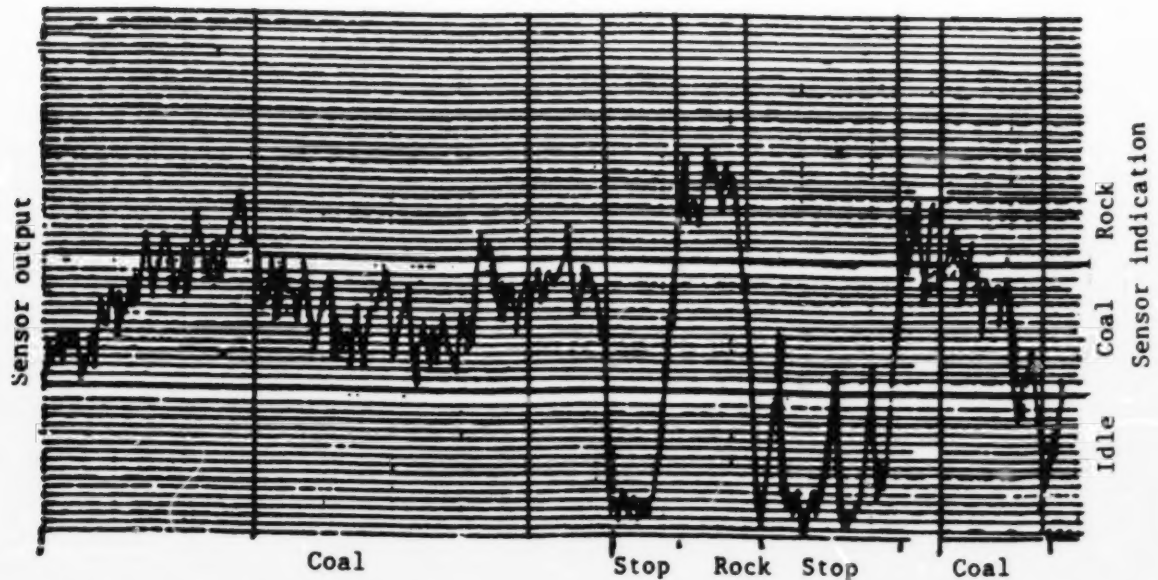


Fig. 11 Example output of a vibration sensor using the time domain technique (17).

Reflectometer

There are differences in the reflectance of coal and other rocks and Figure 12 shows that this difference varies with wave length. It seems likely that a reflectometer using a light source of selected wave length could be used to discriminate between coal and non-coal and thus locate the coal/rock interface (15). However, dust, humidity and moisture variations may prove problematical and little work has been done to pursue this aspect.

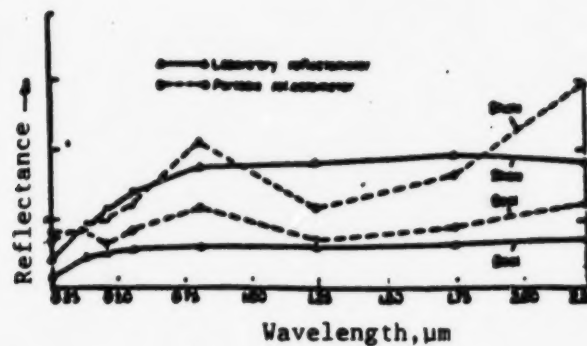


Fig. 12 Differences in the reflectance of coal and shale at different wavelengths (15).

Impact Penetrometer

The relative hardness of rocks can be determined by measuring the rebound energy from an instrumented rod driven against a surface with a known force (15). Such a device, consisting of a spring-loaded plunger with an accelerometer, has been built in the USA and demonstrated to discriminate effectively between soft floor rock, hard roof rock and coal (Figure 13). In this way the coal/rock interface can be detected.

A combination of the impact penetrometer and the reflectrometer has been tested in the USA with limited success (18).

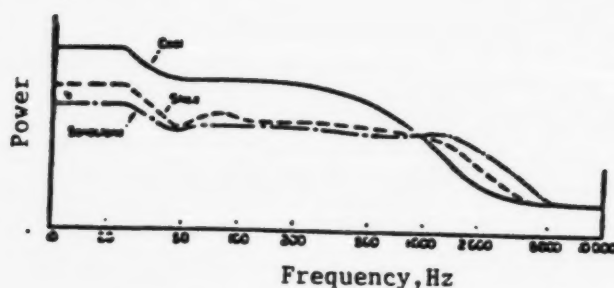


Fig. 13 Frequency composition of responses from an impact penetrometer (15).

Electron Spin Resonance

The potential use of a sensor employing electron spin resonance (ESR) to detect the coal/rock interface and to measure roof coal thickness has been investigated by the Southwest Research Institute USA under a subcontract to NASA (1). The principle of the method is that when material is placed in an appropriate magnetic field, the dipole movement of naturally occurring free electrons interacts with the magnetic field to produce a resonance that can be detected by a radio frequency electromagnetic field. Laboratory measurements of coal and shale samples indicate that a coal/shale interface, and an air/coal interface can be readily detected on the basis of

large differences in ESR amplitude characteristics. In addition a conceptual model of a low frequency ESR system was developed which may be suitable for coal thickness gauging. Analysis suggests that a sensor with 13 mm resolution over a thickness range from 13 mm to 152 mm is possible. Future work is to be directed towards developing a model for demonstration and evaluation.

POST-CUTTING SENSORS

Despite the fact that with an undercutting drum style of selective continuous surface mining machine, the ideal solution is a remote sensing device ahead of the drum which penetrates the uncut strata and determines the depth of the cut-off horizon, the alternative solution could be to monitor the quality of product material passing along the discharge belt of the machine. While there may be inaccuracies in such measurements, it is still possible to adjust the cutter and achieve an overall product quality which exceeds that achieved in present mining systems. There are several methods available to achieve post-cutting control.

On-stream analyzers currently available that sort (discriminate) shale from coal being transported on a conveyor belt are based on either the measurement of specific gravity, or the effective atomic number of coal. The techniques used for measuring effective atomic number are radiometric or electromagnetic, which use both X and gamma radiation and neutron activation.

Neutron Activation Sensor

The most precise yet most complex method for ash analysis is neutron activation. In this technique a uniform bed of coal is bombarded with fast neutrons. These neutrons subsequently collide with the nuclei of the elements in the coal solids. The effect of the collisions is to slow the neutrons down sufficiently until they are captured by a nucleus. This then creates an unstable isotope which then returns to its normal state by emitting characteristic gamma-rays (i.e. decay of an element at its characteristic half-life). It is through measuring the intensity of this characteristic radiation that the elemental composition can be determined.

This is because the radiation emitted by the unstable isotope is a function of the element's atomic number and atomic weight.

One of the instruments available that use neutron activation is GAMMA-METRICS bulk material analyzer (19). The Analyzer utilizes a technique known as PGNAA (Prompt Gamma Neutron Activation Analysis) to measure raw material elemental composition. This nuclear phenomenon has only recently become viable for controlling industrial processes. The PGNAA phenomenon is based on a subatomic reaction between a neutron and the nucleus of any atom. When a thermalized, or slow, neutron approaches close enough to a nucleus, it will be absorbed by that nucleus. This absorption process causes the nucleus to become excited, a condition which is relieved by the nearly instantaneous release of a gamma ray. (See Fig. 14).

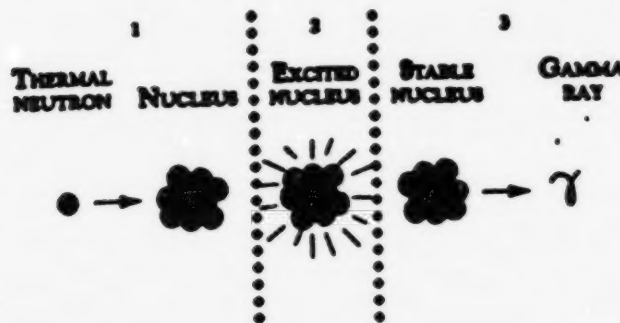


Fig. 14 PGNAA nuclear phenomenon initiated by neutron which generates gamma rays characteristic of the activated element.

Each element responds differently to the neutron activation process in two respects. Some elements are more likely to activate than others: iron, sulfur and chlorine for example, being very active; and carbon and oxygen being very inactive.

The other key distinction among elements is that each one emits, with known probability, a unique set of gamma ray energies. Calcium, for example, produces gamma rays with several different energies, most notably 4.42 and 6.42 MeV.

PGNNA, therefore, requires a means of detecting gamma rays and identifying their energy. This can be achieved by using a scintillation detector. With this detector and additional signal processing equipment, a gamma ray spectrum can be built (shown at right in Figure 14). The spectrum, in turn, can be decomposed into its constituent parts (elements) by using a microprocessor and sophisticated analytical software.

GAMMA-METRICS has developed a reputation for quality and service since its founding in 1980. Actual operating experience has verified its potential as a bulk material analyzer.

Natural Gamma Radiation Sensor

A new electronic discriminator that sorts shale from coal has been developed by Salford Electrical Instruments Ltd. (England) on behalf of the National Coal Board. The new system is based upon the natural gamma emission from materials (stone, shale or coal) being transported on a conveyor belt. (20).

Natural gamma radiation is detected by a probe located beneath the top upper belting of the conveyor, and housed in a purpose-designed enclosure. The natural gamma emissions from the materials on the belt, typically not more than 2 picocuries/g for coal and 20 picocuries/g for stone or shale, are collected and integrated over a period of some seconds. The data, coupled with a prior knowledge of the emission characteristics of the materials carried by the conveyor, are used to determine which material is currently being carried. A suitable radiation shield positioned above the belt improves the sensitivity of the system.

The integrated output of the detector is passed to an associated control unit and displayed on an analogue meter. This reading is related to one of five time-constants selected at the control unit's integral ratemeter, time constants of 2,4,6,10 or 32 sec. may be selected.

An analogue, low-impedence output between 0.4 and 2.0 V dc, relative to the reading, is available from the control unit for use with an external recorder. This is complemented by a relay output with two changeover contacts rated at 100 V, 50 mA, the relay trip point being preselectable at any position over the analogue range of the system. The relay can, therefore, be set so that it is activated when stone or shale is present, and de-activated when coal is detected. The pre-set level can be displayed on the analogue meter. Completely isolated from the system circuitry, power supply and metalwork, the relay contacts can be used to actuate an additional electrical system.

Also contained in the control unit is circuitry providing the system with a high-energy cut-off feature, which can be employed at 500, 600, 800, 1200 or 1500 keV. Additionally, a marker pulse can be introduced into the analogue output whenever the relay is activated, providing a check point on the external recording to denote the dc levels at which the relay becomes activated.

The discriminator is powered from an ac, 50 Hz power source at 110 V or 240 V, via a 2V dc power supply.

Nucleonic Sensors

The most commonly used method for on-stream ash analysis utilizes electromagnetic radiation. This method uses the principle that weakening of the source radiation will be proportional to the atomic number of the elements in the coal-stream. The electromagnetic radiation comes in the form of gamma or x-rays which are produced by radioactive isotopes.

The principle in this method involves measuring the weakening of the radiation by the coal stream. This differential weakening or attenuation is caused by the absorption and scattering of the radiation energy also referred to as quanta or photons. (Figure 15).

Weakening by absorption is known as the photoelectric effect. This type of attenuation is inversely proportional to the intensity of the source radiation, while directly proportional to the density, and thickness of the stream. Moreover though, it is the fact that the attenuation is directly proportional to the atomic number of the coal solids to the fourth or fifth power which makes absorption such an important technique.

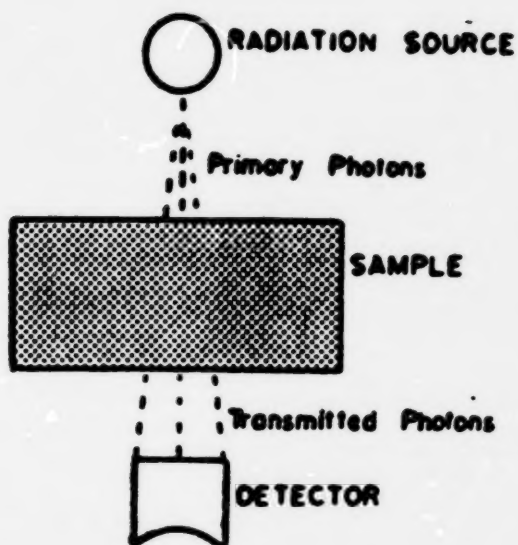


Fig. 15 Transmission geometry.

In this case the source and detector are on opposite sides of the stream. Thus, the majority of radiation which reaches the detector are quanta or primary photons which have passed through the sample without any interactions or collisions. Consequently, by setting the detectors detection level an instrument of this type will measure a single absorption coefficient through an atomic number inference. With the backscatter technique the source and detector are on the same side. However, due to the high probability of a collision, backscatter is only proportional to the atomic number to the first power, and thus is somewhat less sensitive than absorption (Fig. 16).

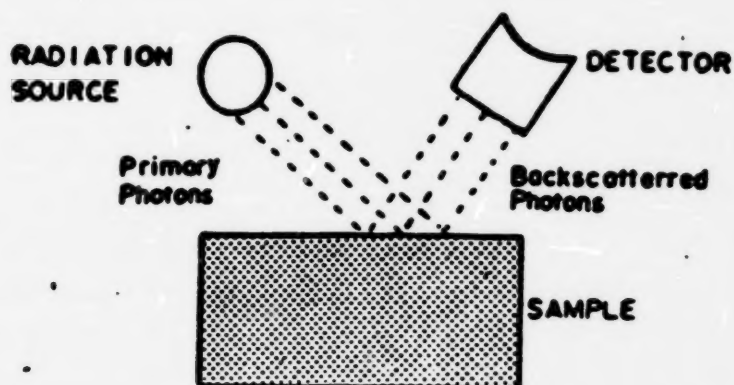


Fig. 16 Backscatter Geometry

Using a backscatter method has an inherent advantage though since additional measurements for moisture, iron, and oxygen are easily accommodated by detection measurements at different energy levels. Since these estimates are necessities in more complex coal materials and for slurry streams, this method is more functional. In contrast, the transmission method requires equipment duplication in order to measure other stream attributes, which then increases capital expense greatly.

Also, it should be noted that when referencing the energy source, high energy usually refers to greater than 250 MeV, while low energy means the source is less than 200 keV in intensity.

Ash analysis using electromagnetic radiation has some other inherent difficulties which are briefly mentioned below.

Firstly, when an instrument is calibrated with a model which has been analytically proven, effective operation of the analyzer is dependent on the assumption that the coal stream attributes do not change. Thus, large variations in the stream elemental composition will require that the analyzer be re-calibrated, such as might occur when coals from different seams are monitored.

Secondly, small amounts of iron mineral matter will require a correction measurement since the iron mineral matter ($Z \approx 26$) and normal mineral matter ($Z \approx 12$) have significantly different atomic numbers. Qualitatively, if no correction is present, the analyzer would estimate a small amount of iron mineral matter to be a large amount of normal mineral matter and the ash analysis would be thrown off.

The on-line analyzers based on nucleonic measurement techniques either commercially available or viable are all quite varied in their intended use, the method utilized, or the country in which the equipment is available (21). The utilization of an on-stream real-time analyzers installed directly on conveyor belts is well documented in the coal industry and is becoming an economic necessity to a greater extent everyday. The Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia developed the COALSCAN 3500 through belt ash monitor. The COALSCAN 3500 uses a computer controlled non-contact nucleonic measuring technique to monitor ash in bulk coal streams (22). The principle of measurement is low Energy Gamma Ray Transmission as depicted in Fig. 17.

The measuring head is mounted on a C-frame assembly which swings out over the belt. The main electronics cabinet and operator displays can be located adjacent to the measurement location or in a control room. Instantaneous ash and cumulative ash contents, together with system status indicators are provided.

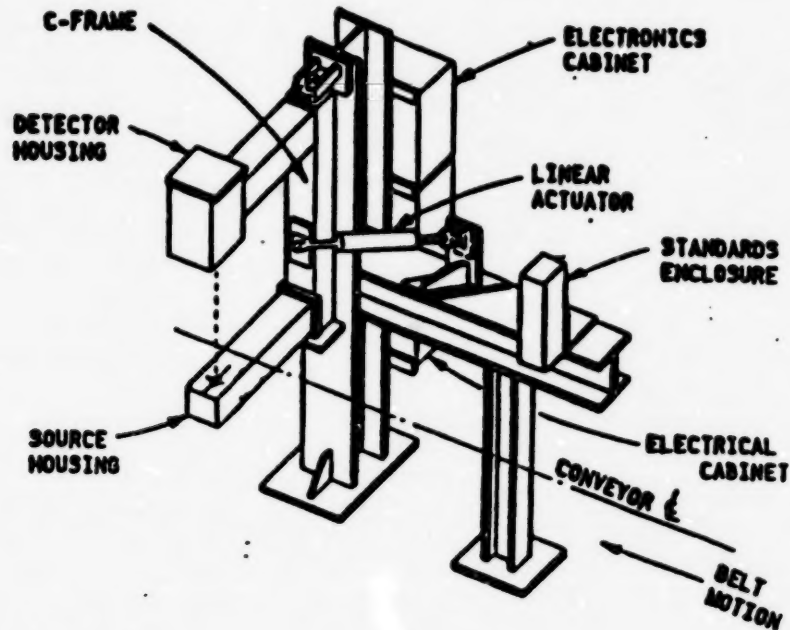


Fig. 17 COALSCAN 3500

The operational features provided by the COALSCAN 3500 include:

- direct measurement on the conveyor belt, ie. no sampling equipment required,
- no interference with the operation of the conveyor belt,
- no contact with the moving coal,
- automatic correction for rapidly changing coal bed depth,
- no top size limitation and can therefore handle run-of-mine coal,
- swing mechanism on the C-frame offers off-belt calibration and automatic standardization, and
- no vertical segregation effects because the radiation passes completely through the coal bed.

The COALSCAN has been used in raw coal preparation plant feed and product application and approximately 8 of these ash monitors have been successfully installed since March 1984. (22).

While accuracy of this instrument is dependent on the variability or range of ash and especially iron content, the accuracy has been reported to be between 0.3 to 1.0 % ash.

The technique of using two gamma ray beams of different energies in the analysis of coal/waste mixtures has been developed at the Mining Research and Development Establishment of the UK's National Coal Board (23).

The uncollided gamma flux transmitted through a mixture of two materials a and b is given by:

$$I = I^{\circ} \exp[-(\mu^a m^a + \mu^b m^b)] \quad (1)$$

where I° is the incident flux,

I is the transmitted flux,

m is the mass loading or mass per unit area, and

μ is the mass absorption coefficient.

This may be reduced to

$$I = I^{\circ} \exp[-(\mu - f \Delta \mu)m]$$

where $m = m^a + m^b$

$f = m^b/m$

$\mu = \mu^a$ and

$\Delta \mu = \mu^a - \mu^b$

Consider now the case of two gamma ray beams of different energies incident on a mixture of coal and stone. In this case, two equations of type (1) apply, viz:

$$I_1 = I_1^{\circ} \exp[-(\mu_1 - f \Delta \mu_1) m]$$

$$I_2 = I_2^{\circ} \exp[-(\mu_2 - f \Delta \mu_2) m]$$

where the subscripts refer to the two different gamma-ray energies and f is the fraction of stone in the mixture. Denoting the normalized transmitted intensity by I^* and taking logs, the following relations are obtained.

$$\ln(I_1^*) = (\mu_1 - f \Delta\mu_1) m$$

$$\ln(I_2^*) = (\mu_2 - f \Delta\mu_2) m$$

Dividing one of these equations by the other gives the ratio

$$R = \frac{\ln(I_1^*)}{\ln(I_2^*)} = \frac{\mu_1 - f \Delta\mu_1}{\mu_2 - f \Delta\mu_2}$$

which, on re-arrangement gives

$$f = \frac{R\mu_2 - \mu_1}{R\Delta\mu_2 - \Delta\mu_1}$$

Thus an expression for f , the stone fraction of the mixture, is obtained which is independent both of the spatial distribution of the coal and stone components and of the mass loading in the beam. The mass loading of mineral matter in the beam may be calculated from

$$m = \frac{\ln(I_1^*)}{\mu_1 - f \Delta\mu_1} = \frac{-\ln(I_2^*)}{\mu_2 - f \Delta\mu_2}$$

For best results, the gamma-ray energies should be chosen such that at one of them the absorption coefficients of the coal and stone are almost equal, while at the other there should be a substantial difference between them. Choosing the energies in this way means that one of the expressions for the mass loading will exhibit only a small dependence on the stone content. It should also be borne in mind that low energy radiation is easily absorbed by minerals and this could limit the maximum mineral loading which can be usefully analyzed. At the other end of the energy scale, gamma-ray

beams are less readily absorbed in passing through large amounts of mineral and hence the sensitivity to changes in mass loading will be poor. One choice of energies which satisfy all of these constraints is 60keV radiation from Am^{241} and 662keV radiation from Cs^{137} .

A schematic diagram of a prototype device operating on the above principle is shown in Figure 18. The detector used is a NaI scintillation crystal viewed by a photomultiplier (PM) tube. The signal from the PM tube is amplified and applied to a single channel analyser (SCA) which spans the photopeak of the radiation. The count-rate is normalized to the empty-belt count-rate and the values of f and m are calculated by the microprocessor.

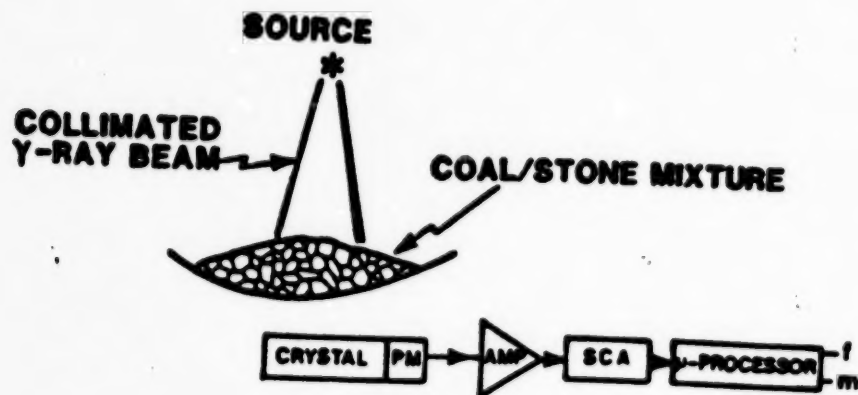


Fig. 18 A schematic diagram of a prototype device of dual stone fraction monitor.

CONCLUSIONS

The development of monitors to provide information for coal-rock interface control is well advanced. The numerous sensors considered here were mainly concerned with data for monitoring the correct position of the drum cutting the roof. Many of these sensors however can be used to maintain the correct position of the drum cutting the floor as is the case of undercutting drum style of selective continuous surface mining machine.

Sensitized picks and pick force sensors can be used on this drum. Some degree of control can be achieved by the nuclear based sensor developed by British Coal. This sensor was found to reliably measure the uncut coal under shale roof rock. The evaluation of the nuclear sensor proved that the technology worked well under shale roof rock because the roof contained a uniform distribution of natural gamma ray emitters. Under sandstone roof rock, gamma emitters were not uniform so that uncut coal measurements could not be determined. The development of the Short Range Horizon Control Sensor (STOLAR), utilizing the electromagnetic wave technology appears to be very attractive for the future remote control of the floor cutting drum of continuous surface mining machines.

It can be concluded that for a coal stream on a conveyor belt commercial equipment is available to discriminate the rocks from coal. Proven industrial applications exist. Adaptation of any of this hardware to continuous surface mining machines, while considered feasible, has not been demonstrated in mine site trials.

Such trials while expensive and time consuming could significantly improve the selectivity of continuous surface mining machines.

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